Suburban Development and Resultant Changes in the Phosphorus Status of Soils in the Area of Ku-ring-gai, Sydney

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Total phosphorus of urban bushland soils from the Ku-ring-gai area in the northern suburbs of Sydney was measured. Sampling sites were located on hillslopes, undeveloped ridgetops, adjacent to creeks and roads, downslope of suburban boundaries and stormwater outlets, and along sewerage lines. All sites were located on soils derived from Hawkesbury Sandstone. Within urban bush valleys, sites adjacent to nutrient sources had significantly higher phosphorus levels than sites remote from nutrient sources. Sites downslope of suburban boundaries were the least affected (average 90 ppm) while sites receiving urban runoff directly had the highest levels of phosphorus (e.g. downslope of stormwater outlets 438 ppm). The area of phosphorus enhancement around nutrient sources was largest for sites located downslope of any source. These results have important implications for the management of urban bushland and the control of exotic plant species.

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INTRODUCTION

Sydney is fortunate to have a substantial area of bushland reserves within the metropolitan area. These bushland areas are regarded as a valuable resource in an urban landscape (Buchanan, 1979; Schoer, 1983), offering important aesthetic, recreational and educational opportunities as well as providing habitat for flora and fauna. With continuing urban consolidation and expansion, these areas face increasing pressure due to their proximity to urban development.

Sydney soils are particularly noted for their low phosphorus level due to the low phosphate content of their parent material. Beadle (1962) reported total phosphate contents of Hawkesbury Sandstones of about 30-40 ppm. Several authors (Beadle 1953, 1954, 1962; Specht 1963, 1975) have suggested that soil fertility is the major determinant of the structure and composition of much of the Australian vegetation, with phosphorus implicated as the limiting nutrient. Some of these studies have also shown that the addition of phosphorus may greatly change the floristics of a community. A major problem in the management of urban bushland is the establishment of exotic, or weed species, which may be advantaged by these higher soil nutrient conditions. The low nutrient levels of the Hawkesbury Sandstone soils make these areas especially vulnerable to any addition of nutrients.

It is generally acknowledged that urban bushland receives an additional influx of nutrients from the surrounding suburban development. Dumped garden rubbish, septic tank effluent, sewage overflows, household drainage and stormwater runoff are thought to be the main contributors (Buchanan, 1979; Adamson, 1980; Clements, 1983). Several studies have also shown that stormwater runoff from urban areas contains significant amounts of sediment and soil nutrients (Bliss *et al.*, 1983; Wright, 1984).

Clements (1980, 1983) has reported higher phosphorus levels of soils from suburban sites in the Sydney area compared to soils derived from similar parent lithology in non-suburban sites. She also found that high soil phosphorus levels were related to the presence of mesomorphic species, both native and exotic. Lambert and Turner (1987) found that overall phosphorus concentrations in leaves were higher in plants from sites near development than from undisturbed sites. The aim of this study was to investigate the distribution of soil phosphorus within urban bushland reserves, the relative contribution of specific nutrient sources to soil phosphorus levels and the extent and direction of the spread of soil phosphorus away from these sources. This knowledge will provide a sound basis for the design of management techniques to control exotic plant species in urban bushland.

METHOD

Site Description

All sites surveyed were within the area of the Municipality of Ku-ring-gai in the northern suburbs of Sydney (Fig. 1). The natural vegetation is typically open-forest, dominated by the *Angophora costata* association, and low woodland, dominated by the *Eucalyptus haemastoma* association (Buchanan 1983).

The area of Ku-ring-gai consists of a central ridge of Wianamatta Shale bounded on the east and west by Hawkesbury Sandstone (Little and Storrier, 1954, Fig. 1). All sites surveyed were on soils of the Hawkesbury Association. Surface soils of the Association are coarse-textured sands of variable depth; these are well-drained, acidic and of low fertility (Walker, 1960).

Sampling Strategy

The study was divided into four sections. The first was a preliminary survey of soil phosphorus distribution within a typical urban bushland valley. This was in order to identify whether phosphorus enrichment occurs generally throughout urban bushland, accumulates in distinct zones or is confined to concentrations around point sources. The results established that there was a significant difference in soil phosphorus levels between the locations sampled, with highest levels adjacent to nutrient sources. Consequently the remainder of the survey examined these nutrient sources to assess their relative contribution to soil phosphorus levels, and the extent and direction of the spread of soil phosphorus around these sources.

For each site the age of surrounding urban development was determined from aerial photographs and information provided by Ku-ring-gai Municipal Council. The location of sewerage lines and drainage easements was determined from Water Board maps and Ku-ring-gai cadastral maps respectively. The presence of each exotic plant species and the level of infestation (light, medium, heavy) was recorded at every site.

Section One

A valley 33 ha in area with an urban catchment of 112 ha (Buchanan, 1983) was chosen for the preliminary survey (valley 1 in Fig. 1). Five transects across the valley were selected by a block random method. Seven sites along each transect were sampled. These covered five site types: undeveloped ridgetop, hillslope below undeveloped ridgetop, suburban boundary, hillslope below suburban boundary, and the creek.

Section Two

Soil adjacent to three creeks in valley systems 1, 4 and 9 (Fig. 1) was sampled. The sites sampled satisfied the factor requirements of a three-way design with two replications. The factors were: individual creeks (three levels); distance from the creek bank (five levels — 2m, 5m, 10m, 15m and 25m) and aspect (two levels — north and south facing). Slope of each transect was measured. Slope angles less than 15° were defined as moderate and greater than 15° as steep.

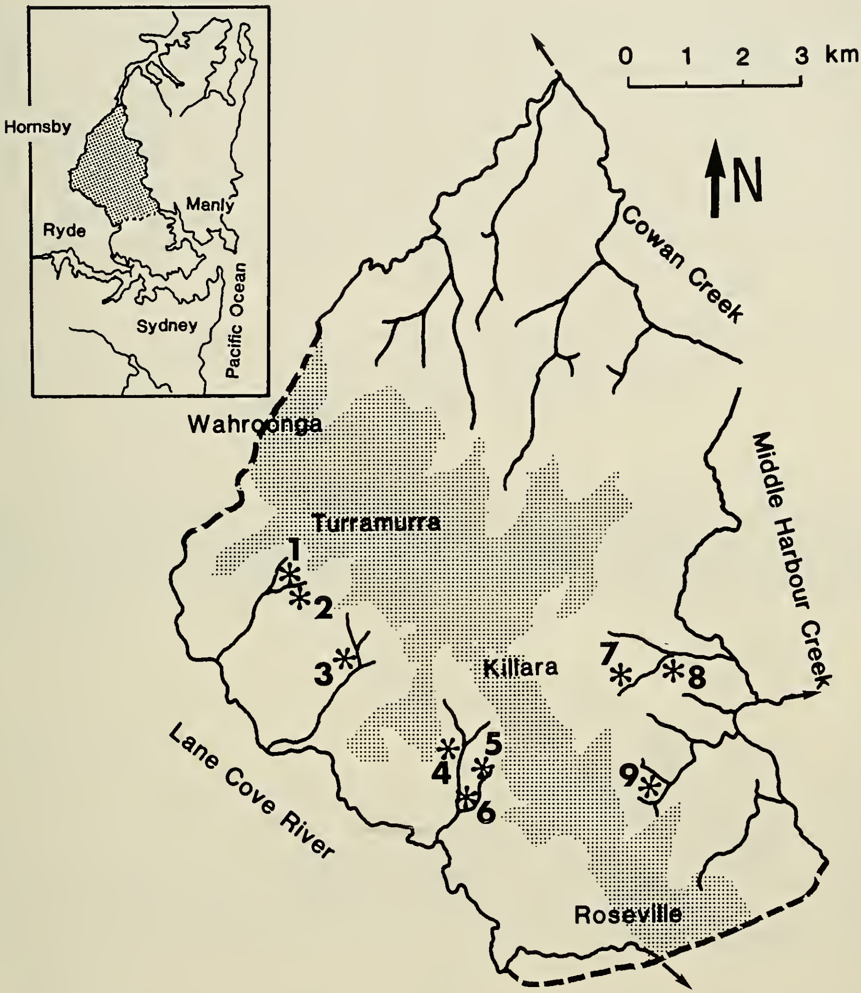

Fig. 1. Map of the area of Ku-ring-gai; the shaded area represents Wianamatta Shale and the unshaded area Hawkesbury Sandstone; * shows the location of valleys in which sampling sites were located. The arrows indicate the direction of flow of the streams. The numbers associated with each valley are referred to in the text.

Section Three

Soil adjacent to six suburban boundaries was sampled from valley systems 1,2,5 and 7 (Fig. 1). Sites sampled satisfied the requirements of a three-way design with two replications. The factors were: age of surrounding development (three levels — 35 years, 15 years and no development); distance from boundary (five levels — 5m, 10m, 20m, 30m and 40m) and aspect (two levels — north and south facing). The boundary was

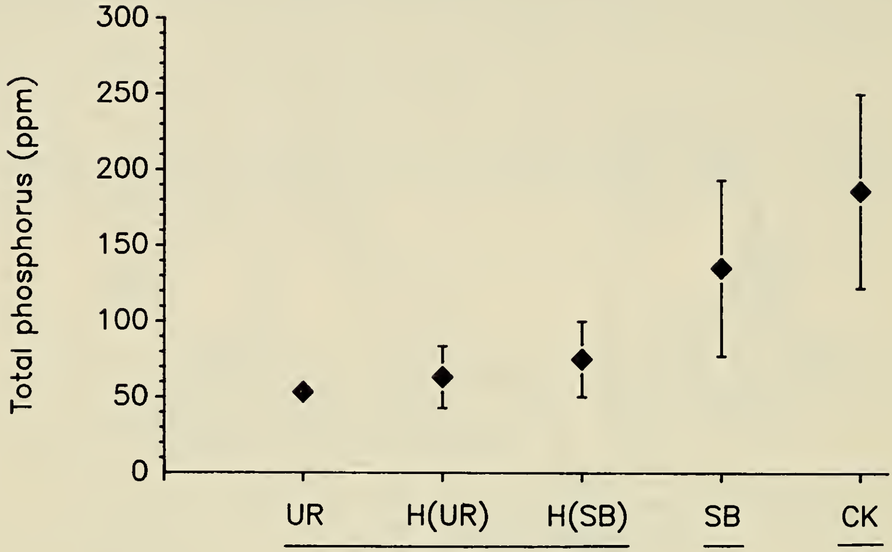

Fig. 2. The average total soil phosphorus of sites within an urban bush valley; UR undeveloped ridgetop; H(UR) hillslope below undeveloped ridgetop; H(SB) hillslope below suburban boundary; SB suburban boundary; CK creek. The error bar shows standard deviation. The solid lines below the x-axis indicate the groupings of phosphorus levels on site types determined by the SNK test ($\alpha = 0.05$).

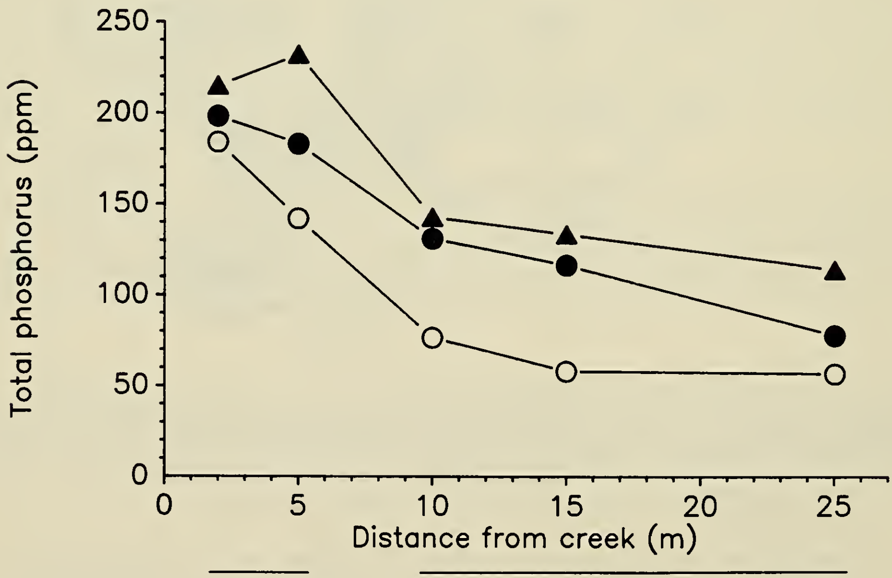

Fig. 3. The average total soil phosphorus of creek sites; O creek 1; • creek 2; ▲ creek 3. The solid lines below the x-axis indicate the groupings of phosphorus levels on distance from the creek determined by the SNK test ($\alpha = 0.05$).

defined as the property edge at developed boundaries and as the ridgetop edge at undeveloped boundaries. The slope of each transect was measured.

Section Four

Soil was sampled below stormwater outlets located in valley systems 1,3 and 7 (Fig. 1), where the surrounding development was at least 30 years old. Samples were collected from 2m, 10m and 30m downslope of the outlet, and 5m and 15m across slope from the outlet at a level 10m below the outlet. Soil samples were collected from sites adjacent to sewerage lines in valley 1 which were constructed in 1973 and ran downslope from the property boundary to the creek. Three samples were collected from directly overlying the sewerage line (located at least 30m apart) and one each from 5m and 10m across slope from the sewerage line. Soil was also sampled from sites adjacent to roads without kerb and guttering which were at least 20 years old, from valley systems 6 and 8 (Fig. 1). Two samples from each of 2m and 10m from the road and one from 30m, were collected from both upslope and downslope locations. There were four replications for each point source.

For sections two, three and four, each sampling site was located at least 50m across slope from any other possible nutrient source. The exception was section four, where stormwater outlets cannot be separated from the suburban boundary.

Soil Sampling and Analysis

At each site five soil cores in a grid of $5m^2$ (section one) or $1m^2$ (sections two, three and four) were sampled. Surface litter was removed and each soil core was collected using an auger of 25mm width and 75mm depth. The five soil cores were than bulked, air-dried and passed through a 2mm sieve to remove stones and litter before laboratory analysis. The samples were analysed for total soil phosphorus following the method of Lambert (1982).

RESULTS

Samples and Analysis

Section One

There was a significant difference in total soil phosphorus between the five site types sampled ($F=10.7$, $df=30,4$, $P<0.001$) (Fig. 2). Undeveloped ridgetop sites and associated hillslope sites below, and hillslope sites downslope of suburban development, had soil phosphorus levels in the range of 30-100 ppm, with a mean value of 63 ppm. Suburban boundary sites showed significantly higher phosphorus levels, with a mean value of 135 ppm, and creek sites were higher again with a mean value of 186 ppm.

Section Two

Analysis of variance showed that total soil phosphorus differed significantly with distance from the creek bank ($F=16.71$, $df=4,29$, $P<0.001$) and among individual creeks ($F=10.7$, $df=2,29$, $P<0.001$). Sites closest to the creek bank (2m and 5m) had significantly higher phosphorus levels than sites located 10m, 15m and 20m from the creek bank (Fig. 3). Soil phosphorus levels at creek two sites were consistently higher than at creek one sites, and levels at creek three sites were consistently higher than at creek two. This could be due to a number of factors such as ratio of developed catchment to valley area, volume of water flow, flood discharge and sediment load. Only information on the ratio of developed catchment to valley area is known, and the differences between these ratios do reflect differences in soil phosphorus between the creeks (creek one, 3.4; creek two, 7.2; creek three, 12.3 (Buchanan 1983)).

Section Three

Sites adjacent to suburban boundaries were found to differ significantly in soil phosphorus levels with age of surrounding development ($F=21.14$, $df=2,29$, $P<0.001$) and with distance from the boundary ($F=5.05$, $df=4,29$, $P<0.01$). Sites adjacent to undeveloped ridgetops had significantly lower soil phosphorus levels than sites adjacent to suburban development (mean value 56 ppm and 83 ppm respectively) (Fig. 4). Although sites adjacent to development 35 years old had generally higher soil phosphorus levels than sites adjacent to 15 year old development, this difference was not significant.

Soils sampled at different distances from the undeveloped boundary showed no significant difference in phosphorus level (t-test: $p>0.05$, $df=6$). In contrast, soils within 20m of the suburban boundary had significantly higher phosphorus levels than soils 20m to 40m from the boundary (mean value 90 ppm and 73 ppm respectively) (t-test: $p>0.05$, $df=38$).

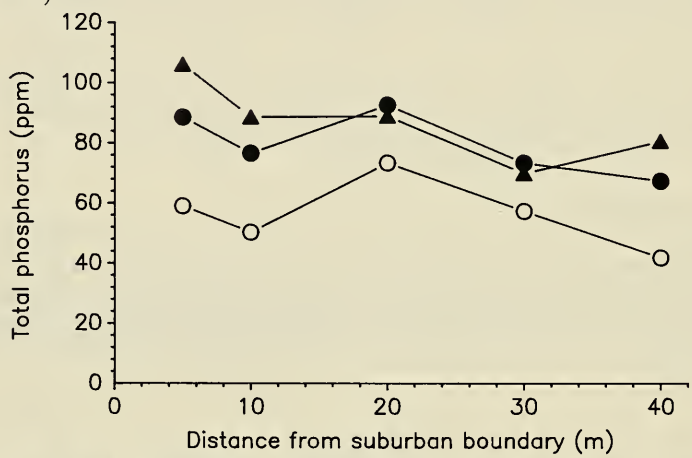

Fig. 4. The average total soil phosphorus of sites adjacent to suburban boundaries; O no development; ● development since 1970; ▲ development since 1950.

Section Four

Sites below stormwater outlets showed no difference in soil phosphorus levels among the spatial sites below each outlet ($F=2.7$, $df=4,12$, $P>0.1$), although there was a significant difference in soil phosphorus among individual outlets ($F=26.7$, $df=3,12$, $P<0.001$). The mean soil phosphorus content of soils below the stormwater outlets was 438 ppm. This is 4-5 times higher than the levels associated with the edge of suburban development and 6 times higher than the levels for hillslope sites of the same suburban valleys. As phosphorus levels for sites located 50m across slope from stormwater outlets in previous sections were significantly lower than levels for sites located only 15m across slope, the affected area can be estimated to between 30m and 100m wide and extending at least 40m downslope from each outlet. Soils overlying sewerage lines had significantly higher phosphorus contents than soils 5m and 10m across slope (mean value 113 ppm and 70 ppm respectively) (Fig. 5a). Total phosphorus was found to be significantly higher for soils downslope compared to upslope of roads ($F=8.35$, $df=1,18$, $P<0.01$) and for soils less than 10m compared to greater than 10m from the road edge ($F=3.99$, $df=2,17$, $P<0.05$) (Fig. 5b). There was no significant difference in phosphorus level among upslope sites (t-test: $P>0.05$, $df=5$). However, sites 2m downslope of the road had significantly higher phosphorus levels than sites 10m and 30m downslope (575 ppm and 163 ppm respectively).

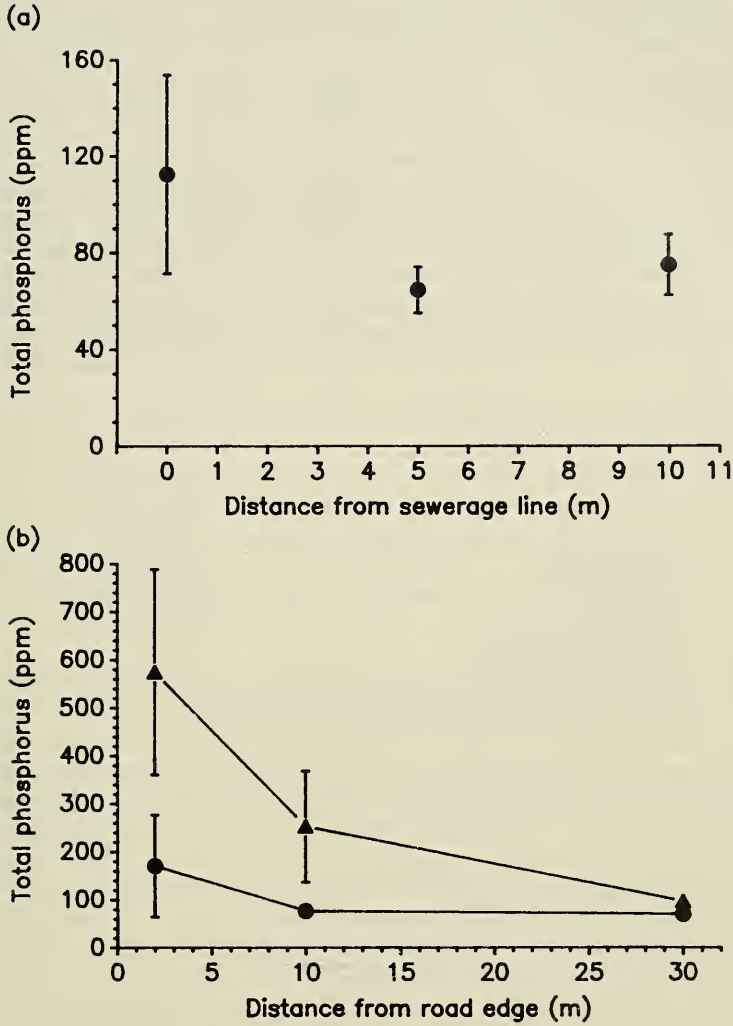

Fig. 5. The average total soil phosphorus of (a) sewerage line sites and (b) road sites; ▲ downslope of roads; ● upslope of roads. The error bar shows standard deviation.

Discussion

The results clearly show that there is an increase in total soil phosphorus within urban bushland areas. There is evidence for local enhancement of soil phosphorus levels, associated with particular nutrient sources, with the level of enhancement depending on both the nature and location of the source.

Sites adjacent to creeks and suburban boundaries were found to be areas of significant phosphorus enhancement. Nutrient input to creeks would come mainly from stormwater runoff and sewage overflows during heavy rainfall. The area of enhancement adjacent to creeks is confined to within 5m of the creek bank, with phosphorus levels within this area approaching 200 ppm. This is considerably higher than for comparable sites in non-suburban bushland. For example, Beadle (1962) found average soil phosphorus levels of 98 ppm in Hawkesbury Sandstone valleys supporting depauperate rainforest. The abrupt change in phosphorus levels between sites 5m and 10m from the creek bank suggests that overbank deposits rather than downslope movement of soil materials are responsible for the increased levels. Observations of flood debris confirm that the area of enhancement corresponds roughly with the zone flooded during heavy runoff events.

There are a number of possible sources of phosphorus associated with the suburban boundary. These include runoff from properties (containing sediment, fertilizers, pesticides, *etc*) and dumped garden rubbish. The relatively small increase in phosphorus levels of these sites, irrespective of age of surrounding development, suggests that these sources contribute only a small amount of additional nutrient to urban bushland. However the location of suburban development on the ridges above bushland areas results in considerable downslope movement of these nutrients. Consequently the area of enhancement extends 20m below the suburban boundary, despite the low level of enhancement.

The topographic location of nutrient sources in urban bushland is critically important in determining the extent of the spread of phosphorus away from the source. Soils downslope of roads, stormwater outlets and suburban boundaries show phosphorus enhancement over a large area. In contrast, soils upslope or across-slope from sources such as creeks, roads and areas of introduced fill, show only a limited area of enhancement. Several studies (Bliss *et al.*, 1983; Wright, 1984) have shown that 80-90% of the total phosphorus in urban runoff is associated with particulates. Thus the movement of phosphorus is associated directly with the movement of soil and plant particles rather than in solution with groundwater.

The largest areas and highest levels of phosphorus enhancement in urban bushland were found to be associated with roads and stormwater outlets. Soil phosphorus levels adjacent to these sources were approximately five times that of suburban hillslope sites (Fig. 6). The area of enhancement downslope of roads and stormwater outlets extended up to 30m and at least 40m respectively from the source. The main contributor of nutrients to these sources is stormwater runoff. This runoff enters bushland via creeks, off paved surfaces such as roads and through stormwater outlets. Most areas of urban bushland have several stormwater outlets located at their boundary and stormwater is released directly onto the hillslope below. Sites subject to stormwater runoff (e.g. creeks, downslope of roads and stormwater outlets) had greatly enhanced levels of soil phosphorus compared to both suburban hillslope sites and sites adjacent to other nutrient sources such as introduced fill (e.g. sewerage lines, immediately upslope of roads) and dumped garden rubbish (e.g. suburban boundary) (Fig. 6). It is obvious that the major source of nutrient enrichment in urban bushland is urban runoff. In unsewered areas, stormwater runoff would be expected to carry an even higher nutrient load.

All sites sampled which had increased levels of soil phosphorus were associated with the presence of weed species. These weed species were not found in areas remote (e.g. more than 100m) from nutrient sources. Several authors have also reported the presence of weed species adjacent to nutrient sources. Buchanan (1983) reported the presence of a band of weeds 2m–5m wide and of moderate intensity along creeks and a weed band associated with the urban boundary of 5m–10m. She also reported dense weeds downslope of road batters consisting of clayey fill while upslope is weed-free. Plumes of weeds downslope of stormwater outlets have been recorded by Buchanan (1983) and Wright (1984).

A simple causal relationship between nutrient sources and the presence of exotic species cannot be assumed. Several factors need to be considered such as the type of exotic species present and other possible forms of disturbance. This is illustrated in

Table 1 where qualitative observations on factors of disturbance and the presence of exotic species at different locations within urban bushland are systemized. Examination of Table 1 shows that an increase in soil phosphorus is usually associated with an increase in soil moisture. Locations where both these forms of disturbance are present are characterized by the presence of weed species such as *Ligustrum sinense* (Small-leaved Privet), *Tradescantia albiflora* (Wandering Jew), *Ipomoea indica* (Morning Glory), *Cardiospermum grandiflorum* (Balloon Vine) and *Lonicera japonica* (Japanese Honeysuckle). In contrast, in areas where mechanical disturbance of the soil and canopy loss are the important factors of disturbance, species such as *Pennisetum clandestinum* (Kikuyu), *Cortaderia selloana* (Pampas Grass), *Rubus vulgaris* (Blackberry), *Eupatorium adenophorum* (Crofton Weed) and *Lantana camara* (Lantana) are found. Thus the addition of nutrient in the form of phosphorus appears to be an important factor in the establishment of weed species in urban bushland areas. When phosphorus addition is combined with other factors of disturbance then weed invasion may result.

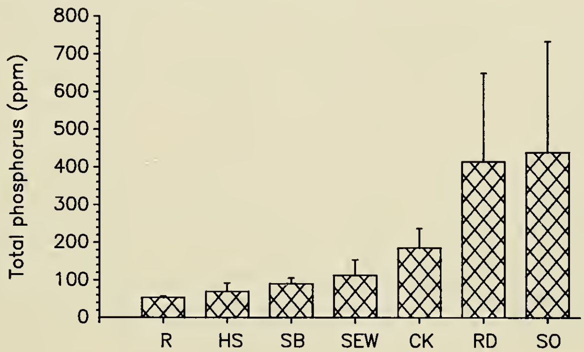

Fig. 6. The average total soil phosphorus levels of all site types sampled; R undeveloped ridgetop; HS hillslope; SB suburban boundary; SEW sewerage line; CK creek; RD road; SO stormwater outlet. The error bar shows standard deviation.

This study has clearly demonstrated elevated levels of soil phosphorus adjacent to nutrient sources within urban bushland. Clements (1983) suggests that a general enrichment of nutrient levels of urban bushland soils also has occurred. However the large natural variation in nutrient levels within the Hawkesbury Association soils, due to interbedding of shale and proximity to the Wianamatta Shale boundary, makes this conclusion doubtful without further sampling. I suggest that in small (*ie* less than 10 ha) bushland areas, a general increase in soil phosphorus levels is likely as affected areas (*ie* those downslope of nutrient sources such as stormwater outlets) expand and coalesce. However in larger bushland areas, where the affected areas are small relative to the total size, soil phosphorus levels will increase only very slowly as soil particle movement and nutrient recycling redistribute the nutrients within the system. Consequently the problem areas of weed invasion will remain confined to soils adjacent to nutrient sources. The most important consequence of this for managers of urban bushland is that reduction of nutrient and sediment loads of stormwater runoff and the control of stormwater release must be a major priority.

TABLE 1

A comparison of factors of disturbance with exotic species present at five locations within urban bushland. Disturbance factors, level of infestation and presence of exotic species are ranked according to total soil phosphorus as determined in this study for nutrient, general knowledge for other disturbance factors and qualitative field notes taken during this study for level of infestation and presence of exotic species. Ranks are from 1 to 5 representing least to most important. Plant nomenclature follows Beadle et al *(1982).*

	LOCATION				
	Suburban Boundary	**Sewerage Line**	**Creek**	**Road**	**Stormwater Outlet**
FACTOR OF DISTURBANCE					
Nutrient	1	1	3	4	5
Moisture	1	1	5	3	4
Soil Turnover	3	5	1	4	2
Canopy Loss	4	3	1	5	2
LEVEL OF INFESTATION	2	1	3	4	5
EXOTIC SPECIES PRESENT					
Ligustrum sinense *Tradescantia albiflora*	2	1	5	3	4
Pennisetum clandestinum *Cortaderia selloana*	4	5	1	3	2
Rubus vulgaris *Lantana camara* *Eupatorium adenophorum*	4	5	2	3	1
Ipomoea indica *Cardiospermum grandiflorum* *Lonicera japonica*	2	1	3	4	5

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